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AN ASSESSMENT OF THE RISKS PRESENTED BY CARBON FIBER COMPOSITES RELEASED FROM MOTOR VEHICLE FIRES

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ABSTRACT

A risk assessment was conducted to estimate the potential losses through 1993 due to the usage of carbon fiber (CF) composites in U.S. motor vehicles, including automobiles and trucks. Motor vehicle fires could conceivably release minute carbon fibers, which might disperse in the atmosphere, penetrate buildings or enclosures, and cause damaging shorts to electronic equipment. Of a total estimated 310,000 vehicle fires per year in the U.S., approximately 94,000 could potentially release carbon fibers. The average mass released was estimated to be about 20 grams per incident, based on forecasts of CF usage through 1993 and experimental tests with burning CF composites.

A methodology was developed to compute estimated dollar losses by county and equipment type, using a Poisson model for the incidence of equipment failures. This approach incorporated data on the geographic distribution of potentially vulnerable facilities, as well as the mean CF exposure levels at which various equipment would fail. The results were then statistically aggregated to produce a national risk profile for estimated annual losses in 1993. The expected loss was $5,567 per year (1977 dollars), and the likelihood of exceeding $500,000 in annual losses was estimated to be at most one in ten thousand. The sensitivity of these results to major input parameters was investigated, and it was found that under extreme worst-case assumptions the annual loss would increase to about $1.5 million.

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1. INTRODUCTION

1.1 BACKGROUND AND OBJECTIVES

Carbon fiber (CF) composites are being considered as an alternative material in the manufacture of trucks and automobiles because of their light weight, high strength, and design flexibility. As their production costs decrease, CF composites are expected to find a considerable market in aircraft, aerospace and industrial applications, as well as in road vehicles. In the case of automobiles, regulatory pressures for increased fuel economy will encourage the use of lightweight materials in the future. However, in spite of the benefits of CF composites, a potential problem has been identified associated with the high conductivity of the carbon fibers. When composite material is exposed to fire of sufficient duration and intensity, it is possible that the epoxy binding material will burn off, releasing individual fibers into the atmosphere. These fibers, if deposited on electronic equipment, could cause shorts in low-voltage circuits, resulting in damage to the equipment and possible economic losses for the facility or community involved. The Department of Transportation has been charged with the task of investigating the risk to the United States as a whole from potential releases of CF in accidental fires in motor vehicles. As a part of the program of risk assessment undertaken by the Department of Transportation, Arthur D. Little, Inc., was contracted to quantify the risks associated with CF composite use in automobiles through the year 1993.

In order to perform the risk assessment, information was gleaned from several other agencies that are conducting parallel investigations, with NASA as the coordinating agency. The data incorporated into the

analysis included fiber release characteristics for burning composites, vulnerability test results for various categories of equipment, and filter penetration experiments which are concerned with the ability of single fibers to enter buildings. However, uncertainties remain in data inputs for certain crucial elements of the risk analysis, which can introduce a substantial uncertainty into the magnitude of resulting risk estimates. Among the areas of greatest uncertainty are the frequency of fire incidents, the quantities of CF that are actually released, and the equipment-disabling properties of fibers. In this report we have attempted to show uncertainties explicitly, to make conservative assumptions where necessary, and to determine the sensitivity of our risk estimates to these uncertainties and assumptions.

The objective of the present DOT study was to assess the future probability of incurring economic losses due to the utilization of carbon fiber composites in automobiles. The major concerns of this study were to project the usage of CF composites in vehicles, to analyze the incidence of vehicle fires, and to develop a national risk profile, with confidence estimates, which would quantify the probability of exceeding various losses in terms of dollars. Many of the methods used in this report have been adapted from a NASA-sponsored risk assessment for CF usage in commercial and general aviation.[1] In particular, the demographic and economic consequence evaluation mechanisms are modified versions of the aviation-oriented methodology. In the course of the study, a simplified methodology was developed for generating the national profile by direct computation. This is described in the next section.

1.2 METHODOLOGY

Risk assessment of carbon fiber releases resulting from automobile fires is different from previous risk assessment work regarding accidental CF releases from commercial aircraft[1] in several ways. First, there are substantially more automobile accidents per year than commercial aircraft accidents. This difference, for example, allows the utilization of an analysis technique based upon the statistics of large numbers. A second difference is that automobile accidents are likely to occur on any public road, which implies that automobile accidents are much more uniformly distributed geographically than commercial aircraft accidents, which generally occur near airports. Finally, the most significant difference lies in the fact that automobile fire accidents result in relatively small amounts of carbon fiber releases (compared to possible releases in commercial aviation) and as a result the failure probabilities for equipment located near an accident are generally smaller than for commercial aviation.

The fact that the individual releases result in failure probabilities that are very small has several implications. It can be shown (see Appendix A) that since each individual fiber or group of fibers has a small but finite probability of causing a failure, and because experiments have indicated that equipment failures obey an exponential probability law, then the details of the release conditions, with the exception of the total amount of fibers released, are relatively unimportant. This is especially true in a situation where equipment is uniformly distributed. The reason for this is that the expected number of

[1] Arthur D. Little, Inc., An Assessment of the Risks Presented by the Use of Carbon Fiber Composites in Commercial Aviation, NASA Contract No. NAS1-15380, Final Report, 1979.

failures can be approximated by a linear function of the amounts released. As a result, each accidental release incident may be characterized by a Poisson distribution for the number of failures. This distribution can be successfully applied to events for which there are a large number of probabilistic trials with a low probability of occurrence in each trial.

Another effect of the low probability of failure is that it makes a simulation approach to risk estimation impractical and difficult to implement. The dominant contribution to determining the number of failures is the probabilistic nature of the individual failures (i.e., the Poisson variation) rather than variations due to accident locations and release conditions, and consequently the simulation approach requires a very large number of Monte Carlo trials in order to develop any confidence in the results. In addition, because automobile fires can occur all over the nation, a simulation would require a data collection effort that would be prohibitively costly.

As a result of these considerations we have developed a method for the present application based on the Poisson distribution instead of a Monte Carlo simulation. This method analyzes primarily the Poisson nature of failure and utilizes numerical calculations of probabilities. The analysis of equipment and facilities is performed on the county level, and the actual probability calculations are based on mixtures of Poisson distributions that apply for each county, amount released and equipment category combination. The validity of this approach is a crucial consideration for the risk assessment. Appendix A presents a rationale for this approach and includes a detailed discussion of the implications of low probability failures.

Essentially the approach consists of the following steps, as illustrated in Figure 1-1:

- A distribution of possible CF release quantities is developed, based upon projected CF usage and several possible fire scenarios.

- For each release quantity, the surface integral of exposure is estimated. It can be shown that the exposure (measured in fiber-seconds per cubic meter) integrated over the area exposed is approximately determined by the quantity released and the fiber settling velocity. Hence there is no need to consider fire characteristics or atmospheric conditions.

- The conditional probability of a random accidental fire occurring in each specific county is estimated as a function of county population.

- For each county in the U.S. the number of facilities in various industrial categories, as well as private residences and community services, are enumerated. Potentially vulnerable equipment is identified within each facility category.

- The expected number of failures for each class of equipment, county location, and release quantity is calculated, using information about equipment vulnerability in terms of exposure.

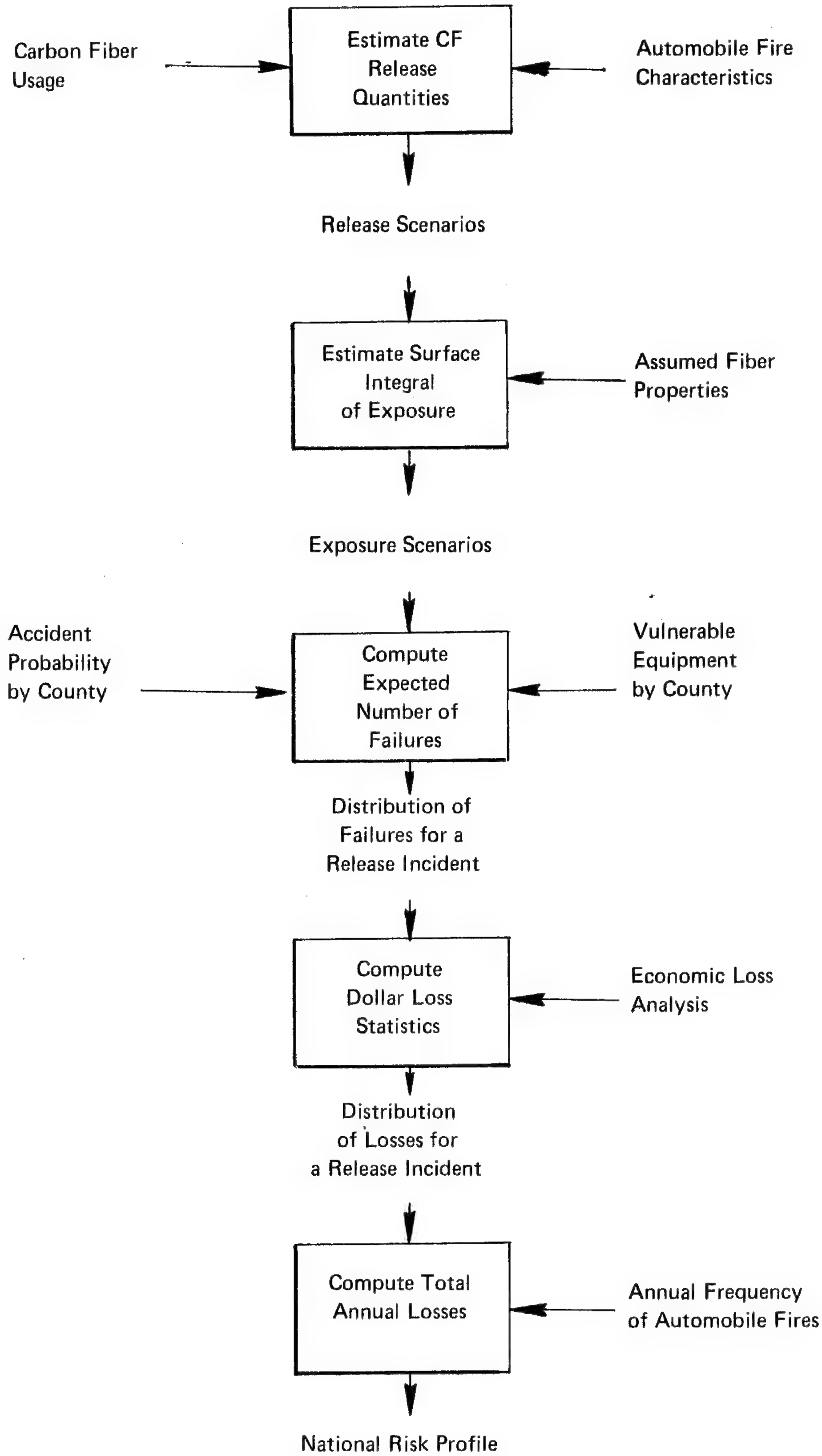


FIGURE 1–1 OVERVIEW OF METHODOLOGY

- Assuming that the number of failures is Poisson-distributed, a probability distribution is generated for the number of failures per release incident, aggregated over all counties and release scenarios.

- The proportion of failures occurring in each equipment category is estimated and economic losses are assessed, resulting in the statistics of dollar losses per release incident.

- Finally, the statistics of annual dollar losses are obtained using the estimated total number of fire incidents per year. On the basis of these statistics a national risk profile is estimated. The national risk profile is a graphical display of the probability of exceeding various levels of dollar loss as a result of the accidental release of CF in a motor vehicle fire.

Chapters 2 to 5 of this report present the various input data required for the risk analysis, and Chapter 6 describes the execution of the above methodology.

1.3 RISK ANALYSIS PRINCIPLES

The concept of risk can be defined as the potential for realization of unwanted negative consequences of an event or activity. In the case of this study, the unwanted negative consequences are the potential economic losses due to electronic equipment failure. The event or activity in question is the operation of motor vehicles utilizing carbon fiber

composites. If risk is due to the presence of some causative agent, such as carbon fibers, then the degree of exposure* is measured by the amount of that agent which is potentially active.

In the past decade, an increasing amount of attention has been paid to problem areas involving activities with uncertain outcomes which might engender large risks. In order to deal with these problems the field of risk management has been created and developed. Risk management is a methodical scientific approach towards dealing with such risks. The quantitative aspects of risk management are often referred to as risk analysis. Examples of the application of this approach are in the areas of nuclear reactor safety and transportation of hazardous chemicals, such as liquefied natural gases.

The practice of risk management involves three basic steps: risk identification, risk measurement, and risk control. Potential risks can be identified through experience, judgment, or experimentation. In the case of the carbon fiber problem the nature of the risk is fairly well understood. The major challenge lies in risk measurement, that is, in determining the frequency of occurrence of events. Thus, the purpose of risk analysis is to create an analytic framework permitting measurement of exposure and risk. Finally, if the measured risk is considered sufficiently great, control measures may be deemed necessary. Control measures would consist of any modifications to the mechanism of risk resulting in a reduction in the measured risk.

*In this case, exposure is the time integral of concentration with units of fiber-seconds per cubic meter.

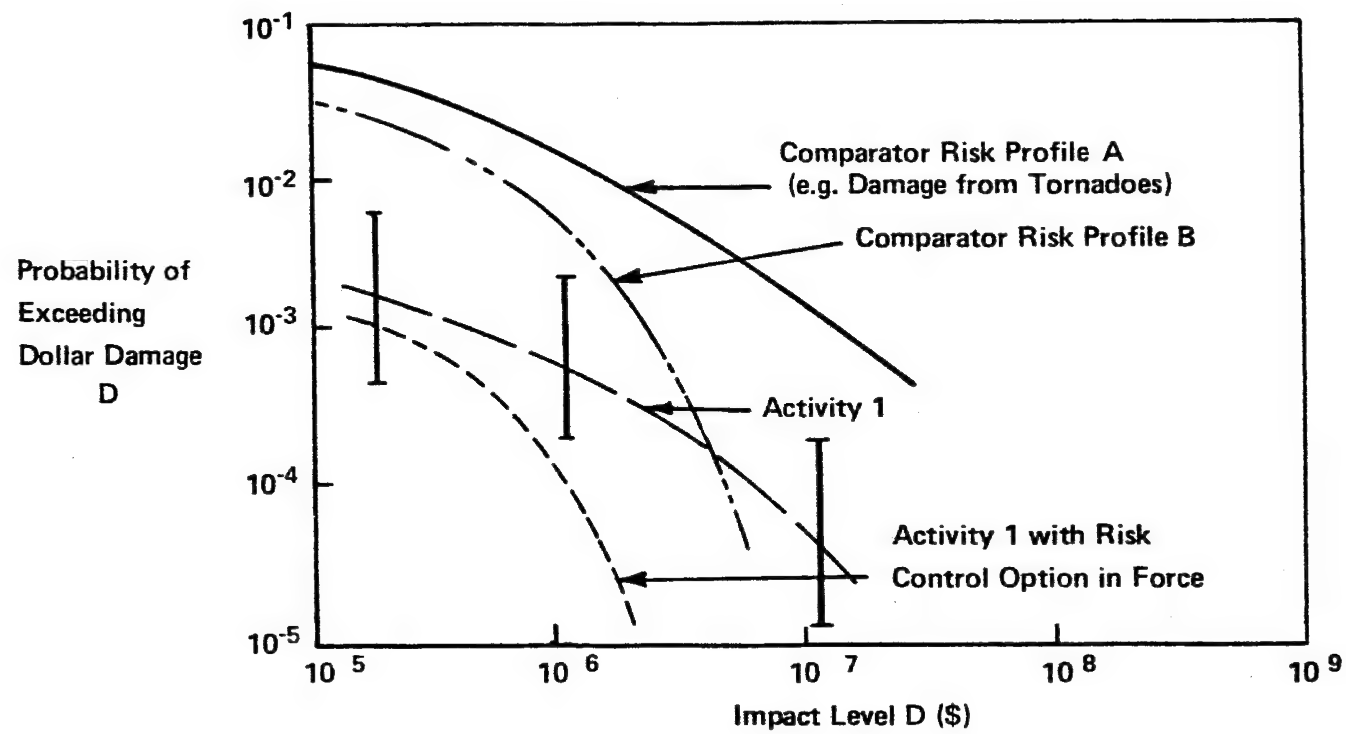
There are various possible representations which can be used to quantify risk. One possible representation is the expected value of losses over a given period of time. However, in order to deal with risks which may fluctuate over a wide range of losses and a correspondingly wide range of frequencies of occurrence, a preferred method of presentation is the risk profile. As discussed earlier, a risk profile is a graphical display of risk identifying the distribution of probability with which various levels of unwanted impacts would be exceeded. A hypothetical example of a risk profile is shown in Figure 1-2. The activity in question is labeled Activity 1 and the risk profile for Activity 1 shows that economic impact can vary from $100,000 to $10 million with probabilities ranging from one in a thousand to one in ten thousand. This risk profile may be compared against other profiles for different types of events, such as the damage from tornadoes. In the diagram two comparator risk profiles are shown. If risk control options are exercised, it may be possible to reduce the risk from Activity 1 as shown by the dotted curve at the bottom. The vertical lines are confidence bounds which show the uncertainty in the estimates of risk. Even though the actual risk may fall anywhere between these confidence bounds, the risk profile can still be used as an effective decision-making tool since it both quantifies in an absolute sense the risks imposed by Activity 1 and permits a comparison of these risks relative to other known risks.

1.4 REFERENCES

[1] Arthur D. Little, Inc., An Assessment of the Risks Presented by the Use of Carbon Fiber Composites in Commercial Aviation, NASA Contract No. NAS1-15380, Final Report, 1979.

<u>FIGURE 1-2</u>

HYPOTHETICAL RISK PROFILE



2. CARBON FIBER USAGE FORECASTS

2.1 INTRODUCTION

Although carbon fiber composite materials are not presently being used in any quantity in motor vehicles, there is considerable interest in the potential utilization of these materials for lightweight, high-strength components. Material substitution is expected to be one of the major strategies of automobile manufacturers in response to increasingly stringent fuel economy regulations. The rate at which CF will be introduced in the automotive industry is difficult to project, due to uncertainty about engineering and design trends and about the future prices of CF composites. In this section we present an overview of information from various sources concerned with the forecast of CF composite usage in automobiles. However, the results of this section must be interpreted as approximate projections. Although various sources of data are discussed for information purposes, the actual data utilized was that which was provided to us by the Transportation Systems Center of DOT. In a later section we present the results of a sensitivity analysis to determine the effect of varying usage levels upon the national risk.

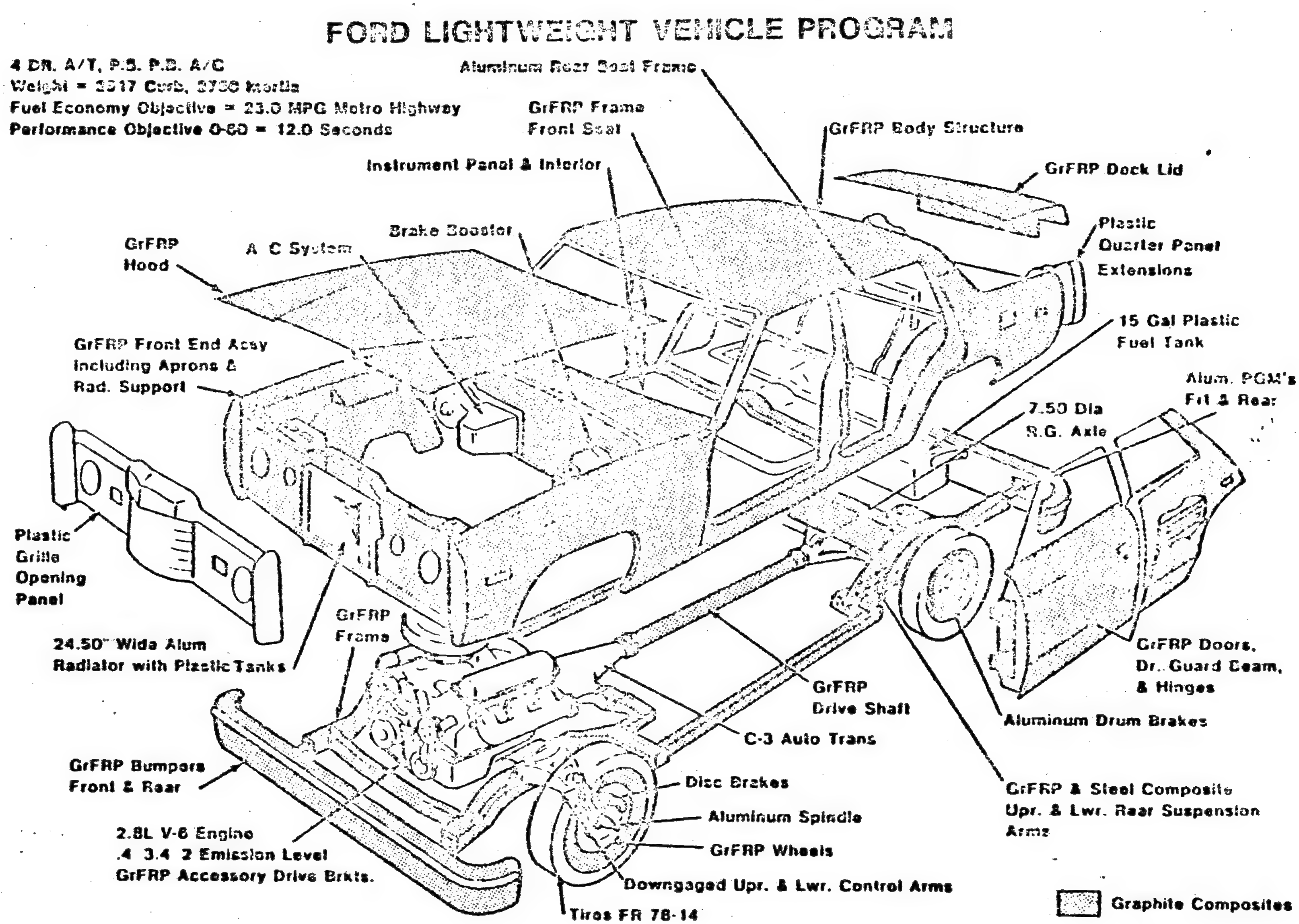
2.2 DEVELOPMENT OF FORECASTS

In order to perform a risk analysis/assessment on the usage of carbon fiber in automobiles, several projections of the quantity of fiber used per car and the total number of cars manufactured per year were examined. It was found that the Argos[1], ECON[2], and NASA[3] forecasts for carbon fiber usage per automobile varied considerably among the various sources. These data had to be sorted to provide a more meaningful forecast rather than

one with a hundred-fold range. For the most part, the rather large discrepancy between the numbers can be explained by the fact that the value of about 41 kg. per auto in 1990 in the ECON report is for graphite composite and not for carbon fiber, whereas the less than 4.5 kg. figure given in the Argos report is for carbon fiber. For automotive applications the percentage of carbon fiber used in a composite is expected to be much less that the 60% used in aircraft applications, and overall may be more in the 20% range. Given this figure of twenty percent, the ECON 41 kg. composite weight would then be reduced to about 8 kg. of carbon fiber per auto in 1990. This figure then is within the 4.5 to 9 kg. range estimated by Argos.

Recently the Ford Motor Company has designed and constructed a "Graphite Composite" car in their lightweight vehicle program. This vehicle makes liberal usage of graphite composites as may be seen from Figure 2-1. Table 2-1 lists the various applications for graphite composites in this vehicle along with the associated weight reductions and quantity of composites used. From this table it may be seen that this vehicle will use only about 23.4 kg. of composite which, at a 20% carbon fiber content, calculates to be just over 4.5 kg. for this vehicle, a value which is consistent with both the Argos and ECON value.

FIGURE 2-1



Source: Ford Motor Company

TABLE 2-1

FORD LIGHTWEIGHT VEHICLE PROGRAM

GRAPHITE COMPONENT WEIGHT SUMMARY

	Steel (kg.)	Graphite Composite (kg.)	Reduction (kg.)
Hood	18.2	6.8	11.4
Door, R.H. Rear	13.8	5.8	8.0
Hinge, Upper L.H. Front	1.0	0.2	0.8
Hinge, Lower L.H. Front	1.2	0.4	0.9
Door Guard Beam	1.8	1.1	0.7
Suspension Arm, Front Upper	1.8	0.8	1.0
Suspension Arm, Front Lower	1.3	0.6	0.7
Transmission Support	1.1	0.3	0.8
Driveshaft	7.9	5.5	2.5
Air Conditioning, Lateral Brace	4.3	1.5	2.8
Air Conditioning, Compressor Bracket	2.6	0.6	1.9
Weight Totals	54.8	23.36	31.5

SOURCE: Ford Motor Company

For 1985, the ARGOS and ECON projections for carbon fiber usage in automotive applications are within a factor of two, 0.27 kg. and 0.45 kg., respectively. Again, a composite weight of about 2.3 kg. is given in the ECON report and as such is reduced to 0.45 kg. of carbon fiber at the 20% fiber usage level. A production rate of 9×10^6 autos per year containing carbon fiber is anticipated at that time. Hence, we arrive at a total usage of 3.2 million kg. in 1985. Also, at that time it is expected that there will be about 120 million vehicles on the road.

Table 2-2 summarizes the estimated carbon fiber usage in automobiles for the period 1985 to 1993.

We expect that the initial usage for carbon fiber composite will be for minor applications such as brackets and hinges. The next type of application is expected to be direct replacement of steel members such as side rails or door beams. Body applications such as the hood are expected to be last due to the difference in handling and repairing techniques between composites and steel. Driveshaft, springs and suspension arm applications are expected to precede body applications if these materials meet the necessary physical property requirements.

TABLE 2-2

FORECAST (1985-1993) FOR CARBON FIBER USAGE IN AUTOMOBILES

YEAR	Carbon Fiber Usage (kg./car)	Est. # Cars Mfgd. With CF (yearly)	% Cars with CF on Road	Total CF Used Yearly (mm kg.)	Avg. Wgt. CF/Car on Road (kg./car)
1985	0.4	9×10^6	7.5	3.3	0
1986	0.5	9.1	14.7	4.5	0.1
1987	0.7	9.2	21.5	6.4	0.1
1988	1.0	9.4	28.0	9.1	0.2
1989	1.3	9.5	34.5	12.7	0.3
1990	1.8	9.6	40.4	16.8	0.4
1991	2.5	9.7	46.1	23.6	0.5
1992	3.4	9.9	51.6	33.2	0.8
1993	4.5	10×10^6	56.9	45.5	1.0

SOURCE: ADL Estimates

As a result of recent information acquired by the Transporation Systems Center[4] (TSC) of DOT, it appears that the amount of CF in surface vehicles will be considerably lower than indicated in Table 2-2. This is due partly to reduced usage projections, and partly to the expected use of glass in combination with CF for composite structures. We have therefore adopted the estimates in Table 2-3 for purposes of the risk analysis. This information, obtained directly from TSC, includes trucks as well as automobiles. The weight of composites placed forward of the firewall, in or near the engine compartment, was estimated separately, since engine fires will be treated as a separate scenario.

2.3 REFERENCES

[1] Technology Assessment of Advanced Composite Materials, Phase 1, Final Report, April 1978, Robert Kaiser, Argos Report for National Science Foundation

[2] Preliminary Economic Evaluation of the Use of Graphite Composite Materials in Surface Transportation, Phase 1 Results, ECON, Inc.

[3] Private Communication, Bob Huston, NASA-Langley

[4] Carbon Graphite Composite Assessment, Status Report No. SS-332-CF-10, Transportation Systems Center, Cambridge, Massachusetts, October 1978

TABLE 2-3

TSC ESTIMATES OF CF USAGE BY THE AUTOMOTIVE INDUSTRY IN 1993*

Class of Vehicles	No. of Vehicles Registered	Total CF Composite Usage (kg.)	CF Composites In or Near Engine Compartment (kg.)
Private autos and light trucks	145×10^6	11.3	4.5
Heavy trucks	3×10^6	68.1	11.3

NOTE: Actual CF weight is approximately 20% of composite weight

*The values projected in this table were used in the risk analysis.

3. ANALYSIS OF ACCIDENTAL AUTOMOBILE FIRES

3.1 INTRODUCTION

The risk to electrical/electronic equipment from the use of carbon fiber composites in automobiles can manifest itself if the carbon fibers are released into the atmosphere. This release can occur as a result of two types of events in the life of an automobile. First, if the car is involved in a fire as a result of a crash, fuel leak, accidental ignition, or arson, and the burning of composite material takes place, some carbon fibers may be released. The second possibility occurs during the disposal operation when the car is finally scrapped. The potential for release is much greater during the scrapping of hundreds of cars than in a single automobile fire; however, because of the controlled nature of the scrapping operation, the risk can be easily controlled by taking appropriate measures to reduce or eliminate it. In the present report, only the uncontrolled release of carbon fibers from a random automobile fire is analyzed.

Because of the conductive nature of the fibers, should they be accidently released and contaminate electrical/electronic equipment, they will cause short circuits and damage to the equipment. Since the distribution of electrical equipment throughout the United States is not homogeneous, the risk associated with a carbon fiber release will be a function of the location of the release. Thus, it is necessary to categorize automobile fire incidence as a function of a parameter which is also related to the geographic distribution of vulnerable equipment.

In the following sections, we have reviewed the statistical data which are available on automobile fires in the United States, and we have chosen the best available data to extrapolate to the entire United States. The method of extrapolation is explained and justified, and the estimated number of automobile fires per year is presented as a function of population distribution.

3.2 REVIEW OF UNITED STATES STATISTICAL DATA ON AUTOMOBILE FIRES

To quantify the incidence of automobile fires in the United States we collected data from several governmental agencies and representatives of the automobile industry. We also conducted a search of the literature for any relevant papers. The following is a list of information obtained:

National Fire Incident Reporting System. This data base on transportation fires, their location, and their causes was begun for five states in 1976 and has recently been expanded to include 21 states. It is being compiled by the NFPCA. The drawback of this data is that several large cities in the states surveyed are not included.

National Fire Protection Association (NFPA). The NFPA's Fire Incident Data Organization (FIDO) is of limited value in transportation fires since most transportation fires do not result in a high enough property damage to be included.

Insurance Companies. Automobile fires are incidental to insurance companies, and they do not collect detailed information on fires as a separate category of automobile accidents.

Accident Facts 1977 Edition National Safety Council. This booklet provides a breakdown of automobile accidents which includes type (head-on, rear-end, etc.), and location (rural or urban). It does not give specific information about automobile fires.

Results of the 1973 National Survey of Motor Vehicle Fires, Fire Journal, March 1975. This paper has information on automobile fire frequency as a function of origin, model year, and make of car.

A Study of U.S. Fire Experience, 1976, Louis Derry, NFPA. This report is published yearly in Fire Journal but deals primarily with property losses and has extremely limited information on automobile fires.

National Highway Traffic Safety Administration, National Center for Statistics and Analysis. Information Systems Division. This source provides excellent data on fatal automobile accidents which involved fires since 1975. However, in the current study, this data base is of limited value because most automobile fires do not necessarily result in fatalities and we are interested primarily in accounting for all fires.

Massachusetts State Fire Marshal's Office. They do not collect information on automobile fires.

Consumer Products Safety Commission. They do not collect information on automobile fires.

Motor Vehicle Manufacturers Association. Their statistical information is handled by the Highway Safety Research Institute at the University of Michigan.

Highway Safety Research Institute, University of Michigan. They are collecting data from fire and police records in Illinois and in Michigan.

From this review we concluded that the best available data for analysis purposes was the Michigan data furnished by the Highway Safety Research Institute. The details of this data base are explained in the next section.

3.3 MICHIGAN AUTOMOBILE FIRE DATA

The Highway Safety Research Institute at the University of Michigan has collected information from fire department records on automobile fires in the state of Michigan for the two-year period from 1976-1977.[1] This data is made up of 27,708 fires of which about 400 are crash fires, and roughly one-third are either arson or suspected arson. The number of fires which occurred over the two-year period in each county are reported.

Because of the way in which the Michigan data is reported, a location is defined here as a county and some logical correlation parameters might be county population, county population density, number of automobiles, or automobile density. Prior to analysis it is not certain how fire incidence might vary with any of these parameters, but it is conceivable, for instance, that a higher automobile density might result in a larger number of crashes and thus a higher automobile fire rate. The automobile fire rate was calculated as a function of several

proposed correlation parameters for each county in Michigan. The data points were fitted by several types of equations (logarithmic, arithmetic, power, exponential) and a linear correlation coefficient was calculated for each to determine the best fit (linear correlation coefficient close to 1) and the best correlation parameter. The best correlation found was between automobile fires annually per county and county population, as shown in Figure 3-1. This relationship was used in all subsequent estimates of frequency of automobile fires.*

3.4 EXTRAPOLATION OF MICHIGAN AUTOMOBILE FIRE DATA TO UNITED STATES

In the previous section the incidence of automobile fires was shown to correlate with the population of a countries based on a two-year study of the state of Michigan. To extrapolate this information to the entire United States it is necessary to assume that the only important parameter in determining the automobile fire rate in a county is the total population of the county. Furthermore, it must be demonstrated that the state of Michigan is somehow typical of the United States.

Michigan is a large, midwestern,industrial state. Its population is slightly less than ten million people, or about five percent of the United States population. The population distribution by county in Michigan is very close to the population distribution for all counties in the United States in terms of both number of counties and total number of people living in counties within a specific population range, as shown in Table 3-1. For example, there are forty-two counties in Mighigan, or 50.6%

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*The relationship derived and utilized here is simply the "best fit" statistical relationship among those studied. No physical meaning should be attributed to the purely statistical relationship used.

FIGURE 3-1 AUTO FIRES PER COUNTY PER YEAR VS. AUTOMOBILES PER COUNTY

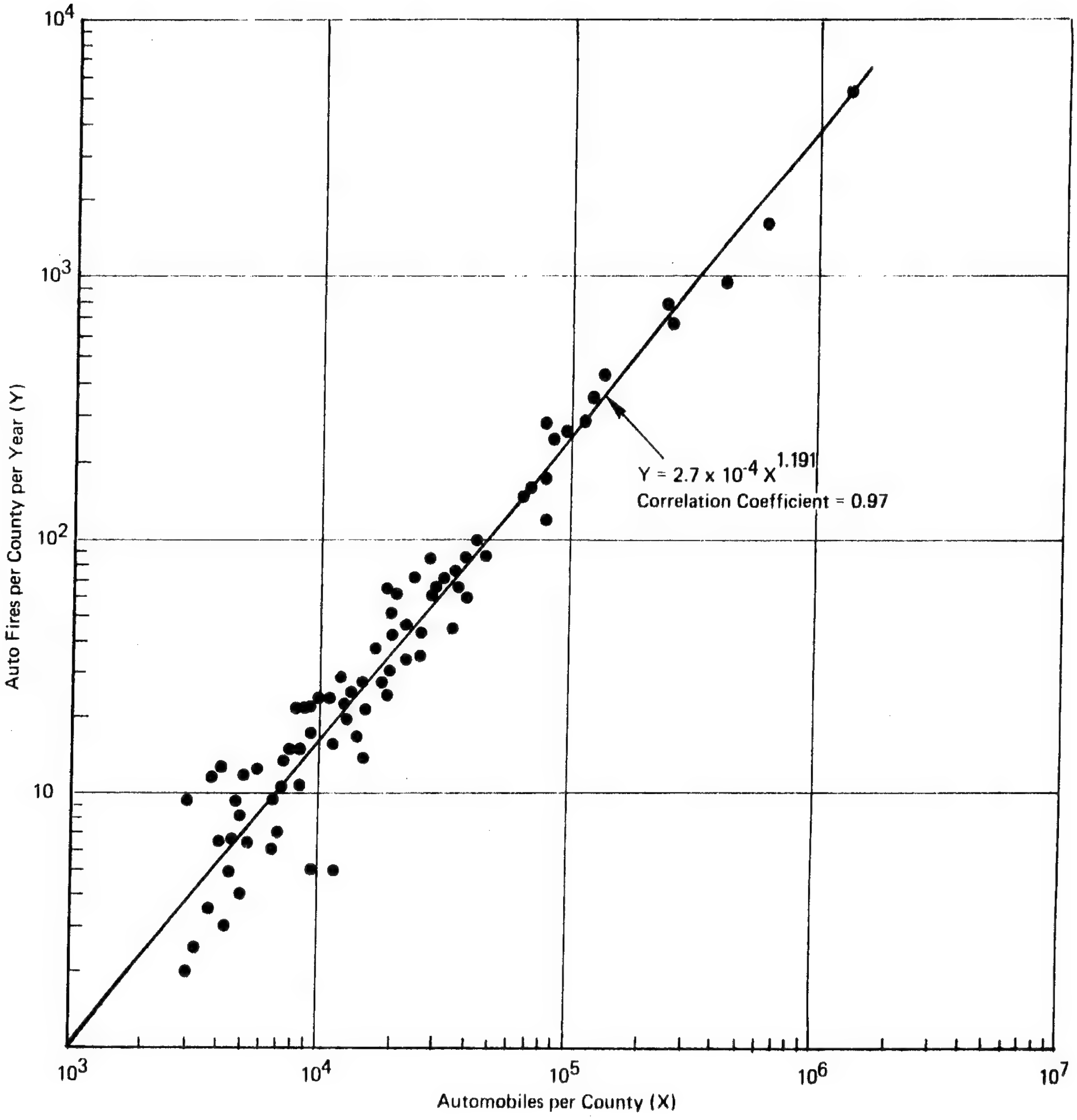

TABLE 3-1

COMPARISON OF POPULATION DISTRIBUTION IN MICHIGAN
WITH POPULATION DISTRIBUTION IN THE UNITED STATES

	United States				Michigan			
County Population	Population	% Pop.	# Counties	% Counties	Population	% Pop.	# Counties	% Counties
< 1,000	19,188	0.01	26	0.83	0	0.0	0	0
1,000 - 4,999	916,401	0.43	278	8.85	2,173	0.02	1	1.2
5,000 - 9,999	3,908,683	1.83	516	16.42	88,312	0.97	11	13.25
10,000 - 49,999	37,821,781	17.75	1,600	50.91	1,123,722	12.33	42	50.60
50,000 - 99,999	23,867,914	11.20	341	10.85	800,541	8.78	13	15.66
> 100,000	146,517,033	68.77	382	12.15	7,101,948	77.90	16	19.28

of the counties in Michigan, where the county population is between 10,000-49,000 people. This is compared with 1,600 counties, or 50.9% of the counties in the United States which have the same range of population. Similarly, 77.9% of the people in Michigan live in counties where the population is over 100,000 people compared to 68.77% in the United States. The population distribution in Michigan tends to be slightly more concentrated in large, urban areas than the United States as a whole, but, assuming that there is no error in the correlation curve developed in the previous section, the total number of automobile fires in the United States can be extrapolated from that curve.

To determine the total number of automobile fires in the United States and their locations, the relationship developed earlier in this section between county population and automobile fire incidence was used. The average number of automobiles per county for each of the six county population ranges was determined by dividing the total population in that range by the number of counties in the same range and assuming two persons per automobile. Then the number of automobile fires per county was computed from the regression equation, and the total number of fires per year in each county population range was determined by multiplying the automobile fires per county by the number of counties. The resulting figures are shown in Table 3-2.

Based on this extrapolation of Michigan data we predict that approximately 260,000 automobile fires occur in the United States every year. This is less than the 325,000 automobile fires per year predicted

TABLE 3-2

EXTRAPOLATION OF
AUTOMOBILE FIRES PER YEAR

COUNTY SIZE	# OF COUNTIES	AUTOS/COUNTY	FIRES/COUNTY	# OF FIRES
< 1,000	26	370	0.31	8.0
1,000 - 4,999	278	1,650	1.83	509.8
5,000 - 9,999	516	3,800	4.95	2,555.9
10,000 - 49,999	1,600	11,800	19.10	30,555.9
50,000 - 99,999	341	35,000	69.72	23,774.0
> 100,000	382	192,000	529.4	202,226.9
	3,143			259,630.

by the NFPCA based on a 26% sample of U.S. population, but because of the uncertainty in both methods of prediction, the difference is not significant. It is interesting to observe the location of the automobile fires; about 78% occur in counties where the population is over 100,000. For risk analysis purposes, the above results were converted to give the conditional probability of a random automobile fire occurring in a county of given population. These probabilities appear in Table 3-3.

At the request of TSC, heavy and light trucks were also included in the risk analysis. Light trucks were included in the category of automobiles, and the estimated number of fires annually was therefore increased from 260,000 to 310,000 for this category. For heavy trucks, it was assumed that the accident probability by county was related to the number of trucks registered by the same formula that was used for automobiles. The resulting accident frequencies for both vehicle categories are shown in Table 4-1 in the next chapter.

3.5 REFERENCES

[1] Personal Communication, James O'Day, Highway Safety Research Institute, University of Michigan.

TABLE 3-3

CONDITIONAL DISTRIBUTION OF COUNTY POPULATION

GIVEN THAT AN AUTOMOBILE FIRE OCCURS IN THE COUNTY

COUNTY POPULATION	PROB. THAT A RANDOM FIRE OCCURS IN THIS COUNTY CATEGORY
< 1,000	3×10^{-5}
1,000 - 4,999	0.002
5,000 - 9,999	0.010
10,000 -49,999	0.12
50,000 -99,999	0.09
>100,000	0.78

4. CARBON FIBER RELEASE CONDITIONS

4.1 INTRODUCTION

Given that an automobile fire has occurred and that CF composite was involved, in order to estimate the resulting damage it is necessary to know the potential exposure of the surrounding area to carbon fibers. The phenomenon of CF release and dispersion involves a complex chain of events, and to physically model these events would require a knowledge of the fire parameters such as pool size, duration, and amount of fuel burned, as well as the weather conditions at the time of the accident, including wind speed and direction and atmospheric stability class. Since these parameters would be difficult to specify in the case of randomly located automobile fires, we have adopted a simplifed methodology, as described qualitatively in Chapter 1 and in detail in Appendix A, which circumvents the need for most of this information. The only data necessary are the total amount of CF released in the fire, and due to the assumption of Poisson-distributed failures, fire and weather characteristics become superfluous. This chapter describes the derivation of a probability distribution for the amount of CF released.

4.2 ESTIMATES OF AMOUNT RELEASED

Based upon previous work by the Transportation Systems Center, we arrived at a classification of automobile fire incidents into three main categories (see Table 1):

- Engine compartment fire (62%)
- Passenger compartment fire (30%)
- Entire vehicle consumed (8%)

For the engine compartment, TSC estimated* that 35% of the fire incidents would be severe enough to release carbon fibers from structural components. Passenger compartment fires are not expected to release any CF because CF will rarely be used in the passenger compartment. For the third category, it was assumed that all incidents would release carbon fibers. The frequency of occurrence for these categories (shown in parentheses above) represents the best estimates possible from limited data available to TSC. For heavy trucks, the relative frequencies estimated for engine fires and total conflagrations were 74% and 26% respectively.

Forecasts of the utilization of CF composites in automobiles have been developed in Chapter 2. The carbon fibers comprise about 20% by weight of the CF composite used in the auto industry. TSC also estimates that at most 1% of the CF would actually be released in a fire. These estimates are reflected in the release quantities shown in Table 4-1. From the projections in Table 3-2, we obtained the chance that an automobile fire will involve a vehicle carrying CF (e.g., 57% chance in 1993). For heavy trucks, it was assumed that all would contain CF. Note that the incident frequency estimates in Table 4-1 may carry as much as a 50% error, due to the accident probability extrapolation technique described in Chapter 3.

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*"Carbon Graphite Composite Assessment." Status report SS-332-CF-10, Transportation Systems Center, Department of Transportation, Cambridge, Massachusetts, October 1978.

TABLE 4-1

CF Release Scenarios and Estimated Frequencies (1993)

VEHICLE CLASS	RELEASE SCENARIO	CF RELEASED (KG)	NO. OF INCIDENTS* PER YEAR	% OF TOTAL FIRES*
Auto and light truck	engine fire	0.01	68,200	22%
	vehicle fire	0.023	24,800	8%
	Total		93,000	30%
Heavy truck	engine fire	0.023	1,036	74%
	vehicle fire	0.14	364	26%
	Total		1,400	100%

*Based on 310,000 fires per year for autos and light trucks and 1,400 fires per year for heavy trucks (TSC estimate).

5. DEMOGRAPHIC ANALYSIS OF VULNERABLE FACILITIES

5.1 INTRODUCTION

The national risk profile for economic losses resulting from accidental carbon fiber releases from motor vehicles was based on the demographics of facilities with vulnerable equipment. A set of parameters was selected to describe each U.S. county for the purposes of the risk analysis presented in Chapter 6. These parameters pertain to demographic data which are readily available from published sources. The economic analysis of failure consequences was derived from an ongoing NASA study of CF risks in aviation.*

5.2 METHODOLOGY

The first step in the analysis was to represent the facilities considered to be potentially vulnerable by a demographic category such as households or the Standard Industrial Classification (SIC) code for businesses. For several other facility categories, indices were required where actual data on facilities were not available; for instance, population was used as a surrogate to measure the amount of police and fire protection services. Table 5-1 shows the facility categories and the demographic data category used to represent the facility. Table 5-2 shows the data sources for each demographic data category.

The transformation of facility categories from the economic analyses to demographic data categories involved some aggregation. The general

*NASA sponsored Phase II Analysis, Arthur D. Little, Inc., December, 1979 (contract # NAS-1-15380). In preparation.

TABLE 5-1

FACILITY AND DEMOGRAPHIC CATEGORIES

Facility Type	Demographic Data Category
Households	Families
Police Protection Services	Population
Fire Protection Services	Population
Post Office Sorting Centers	Population
Subways	Number of Rapid Transit Vehicles
Commuter and Intercity Railroad	Railroad Terminals
General Manufacturing	SIC Code 19
Manufacturers of Electronic Equipment	SIC Codes 3573, 3650, 3660, 3670
Telephone Company Switching Facilities	Families
Radio and Television Broadcasting	SIC Codes 4830, 4890
General Merchandise Retailers	SIC Codes 5310, 5600, 5700, 5900
Retail Grocers	SIC Code 5410
Financial and Insurance Services	SIC Codes 6020, 6100, 6200, 6300
Computer Services	SIC Code 7370
Electronic R&D Firms and Universities	SIC Codes 7391, 8220
Hospitals	Number of Hospital Beds
Airport Services	Number of Air Carrier Operations - 1977
Automobile and Truck Assembly	SIC Code 3710

TABLE 5-2

DEMOGRAPHIC DATA SOURCES

Demographic Data Category	Data Source
SIC Data	U.S. Census Bureau, 1976 County Business Patterns
Families, Population, Number of Hospital Beds	U.S. Census Bureau, 1977 County and City Data Book
Number of Rapid Transit Vehicles	American Public Transit Association
Railroad Terminals	The Official Railway Guide, North American Passenger Travel Edition, July/August 1979
Number of Air Carrier Operations - 1977	U.S. Department of Transportation, Federal Aviation Administration, Terminal Area Forecasts, Fiscal Years 1979-1990

manufacturing category includes equipment classes identified in specific manufacturing environments which were taken as representative of the level of vulnerable equipment in all manufacturing plants.

Given the data categories for facilities, the amount of activity, in terms of number of pieces of equipment in each county, was determined from scaling factors. These scaling factors included number of employees in a SIC category, population, families, etc. For each facility surveyed in the economic analysis, the number of pieces of equipment and the value of the scaling factor for that facility were determined. From the survey, a factor could be developed such as one piece of equipment class x for every 1,000 employees in SIC category y. In this manner, the number of pieces of equipment in each category of vulnerable equipment in each facility category was determined. Appendices C and D contain listings of the equipment categories, with the scaling factors and demographic data index used for each category.

For each category of equipment, associated with the number of pieces are the mean dosage for failure, the transfer functions for outside to inside CF exposure, and the dollar cost per failure. For convenience in the risk computation, described in detail in Chapter 6, the mean dosage for failure and the transfer functions were combined to develop the effective mean outside dosage $\bar{E}$ for failure. When there was a range of transfer functions depending on building characteristics, the arithmetic mean of the high and low transfer factors was used; this procedure results in a number of about the same order of

magnitude as the high end of the transfer function range, which is a consistently conservative assumption. Equipment categories which had equivalent $\bar{E}$ values and equivalent demographic data categories were combined for efficiency in computer processing. The dollar cost per failure of one piece of equipment was derived as the weighted average of the unit costs for each equipment category.

Given the estimate of the number of pieces of equipment for each facility category and equipment type, the computer procedure described in Chapter 6 could be implemented, providing probabilities of equipment failure for each category. The risk profile for dollar losses was derived by combining these probabilities with the dollar loss per failure of equipment. These losses were taken as the sum of the equipment repair and facility disruption costs per failure of equipment. In theory, this procedure could overestimate losses if the expected number of pieces of equipment failing in a single facility were greater than one; in that case the facility disruption cost, which might not increase beyond the first equipment failure, would be overestimated. However, with the CF releases being very low relative to the $\bar{E}$ values, the expected number of equipment failures in any facility would always be lower than one. Appendix C shows the estimated dollar losses per equipment failure.

6. DEVELOPMENT OF NATIONAL RISK PROFILE

6.1 INTRODUCTION

This chapter describes the methodology used to determine the national risk profile and presents an interpretation of the results. The methodology utilized a computer model to calculate the probability distribution for the consequences of a single accident. These single accident results were then extrapolated to obtain a national estimate of expected annual losses. The interpretation of the computer output was based on standard statistical results concerning the aggregation of a large number of individual random variables.

The remainder of the chapter is divided into four sections. Section 6.2 presents the methodology and results for the potential economic losses in a single automobile accident. The mathematical basis for the methodology in this section is presented in the appendices. In Section 6.3, the results for a single incident are extrapolated to an annual risk profile. The extrapolation technique uses the distribution of dollar losses in a single accident to derive an annual dollar loss distribution based on an expected 94,354 accidents per year involving CF composites. In Section 6.4, results of a sensitivity analysis are presented. It is noted that the change in annual dollar loss probabilities with respect to the changes in input parameters, such as release amounts, can be represented by a very simple mathematical relationship. Finally Section 6.5 contains a summary discussion of the results.

Most of the analytical details inherent in the methodology are presented in the appendices. There are, however, some fundamental methematical relation-

ships that control the results developed in this report. These relationships are presented below to emphasize their importance in the final analysis. A glossary of symbols used in the relationships discussed in this chapter is presented in Table 6-1.

The first key relationship is between λ, the expected number of equipment failures in an accident, and such parameters as the amount of carbon fibers released, the equipment vulnerability, and the density of facilities. For any given county and equipment class, the expected number of equipment failures per accident is proportional to the amount of carbon fibers released and the density of facilities, and is inversely proportional to the mean exposure to failure for the equipment. The actual computation of λ is done by summing up contributions from each county in the U.S. and from each equipment class. The mechanics of these computations and the determination of the probability distribution of the number of failures are presented in Appendix A.

The second set of relationships links the mean and standard deviation of the dollar loss in a single accident to the parameters of the distribution for the number of equipment failures in an accident. These relationships are based on standard formulae for conditional expectation, and they can be found, for example, in Parzen, E., Stochastic Processes, p. 55. The equations imply that the expected value of L, the total dollar loss in a single accident, is proportional to λ, the expected number of equipment failures in an accident, and that the variance of L has two terms, one which is proportional to λ and one which is proportional to the variance of the number of failures per accident.

TABLE 6-1

GLOSSARY OF SYMBOLS

$\overline{E}$	=	Mean outside exposure to failure
N_o	=	Number of equipment failures in an accident
L	=	Total dollar loss in a single accident
X_o	=	Dollar loss resulting from a single equipment failure
λ_j	=	Expected number of equipments of type j that fail given an accident
p(i)	=	Probability that i pieces of equipment fail in an accident
$\overline{L}$	=	Total dollar loss annually for all accidents
M	=	Number of accidental failures involving CF nationally
λ	=	Expected value of N_o
E	=	Expectation
n	=	Dummy variable to denote number of events
X	=	Dummy variable for dollar loss
Var	=	Variance
$(X\|n)$	=	Variable X given dummy value n
Y	=	Dummy variable for dollar loss per accident

The final set of important relationships links the statistics of the total annual dollar loss for all accidents to the statistics of the dollar loss in a single accident. These results are based on the same type of conditional expectations relationships referred to above. The expected value of the annual dollar loss is proportional to the number of accidents per year and the expected value of the dollar loss per accident. The variance of the dollar loss per year is approximately proportional to the variance of the dollar loss per accident and the expected number of accidents per year.

To convert the statistics of annual dollar loss into a distribution, some standard statistical methods are used. The results obtained and the outcome of a sensitivity analysis, are presented in the remainder of the chapter.

6.2 COMPUTATION OF LOSSES PER INCIDENT

The computation of the dollar losses per automobile accident is performed in two separate steps. In the first step, a probability distribution of the number of failures contingent upon a single accident is calculated. In the second step, the statistics of the dollar losses (rather than the number of failures) are computed.

An analytic methodology was developed to compute the distribution of the number of failures contingent on a single fire accident. The methodology is based upon the fact that for a given county and equipment class, the number of failures is approximately Poisson distributed. This

is due to the extremely low probability of equipment failure at the levels of exposure typically computed for automobile fires. Because the dominant variation in economic losses is due to the Poisson failure process, this methodology does not require detailed modelling of release conditions or accident locations. As shown in Appendix A, the expected number of failures per accident is directly proportional to the geographic density of equipment and the amount of fibers released and inversely proportional to the equipment's mean failure level, $\overline{E}$.

Implementation of the Poisson methodology required tabulation of data for approximately 3,000 counties in the United States, 81 equipment categories, and several possible release amounts. To handle these data, a computer model was developed and used to determine the distribution of failures contingent upon a single fire incident. Figure 6-1 describes the logical flow of the model and its extrapolation to the national level. As explained in Appendix A, the model tabulates a mixture of a large number of Poisson random variables. There is a separate random variable for each combination of county, equipment category and amounts released. The model adds up the probabilities of any number of failures given each of these possible combinations and weighs them by the appropriate conditional probability of that scenario. The result is the probability that, given an accident in some county, a given number of failures will occur. This distribution is presented in Table 6-2.

The next step in the analysis was to develop the distribution of dollar loss given an accident. The mean and variance of the dollar losses per accident depend on the statistics of the number of failures and of

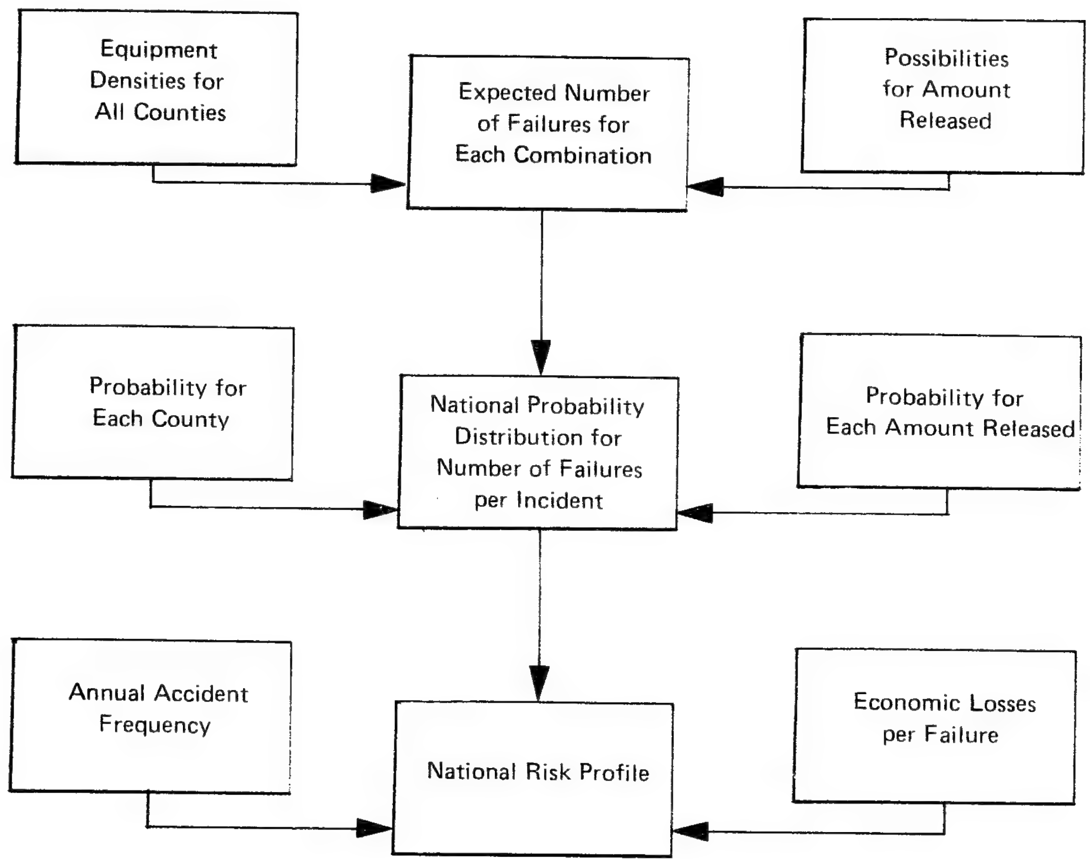

FIGURE 6–1 RISK ANALYSIS PROCEDURE

TABLE 6-2

PROBABILITY DISTRIBUTION OF NUMBER OF FAILURES GIVEN AN ACCIDENT
(1993)

Number of Failures	Probability
0	.99952
1	4.834×10^{-4}
2	1.496×10^{-6}
3	1.6×10^{-8}
>4	~0
Mean	$.4854 \times 10^{-3}$
Standard Deviation	.0222

the dollar loss per failure. For example, if there were five equipment failures, then the expected value of the dollar losses in the accident would be five times the expected value of the dollar loss per failure, and the variance would be five times the variance of the dollar loss per failure. The actual mechanics and results of the computation are as follows:

The computer model described earlier provided the values of λ_j, the expected number of equipment of type j that failed given an accident. On an aggregate basis, the λ_j's represent failure rates for the given equipment classes and the conditional probabilities that any given failure is of type j. Thus

$$\text{Prob(Equipment Type j Fails}|\text{Some Equipment Fails)} = \frac{\lambda_j}{\Sigma\lambda_j}$$

Using this probability function together with the economic loss estimate described in Chapter 5, we developed a distribution for the dollar loss per failure, X_0. We then used the following equations to find the mean and variance of L, the total loss per accident.

$$\begin{aligned} EL &= (EX_0)\,(EN) \\ \text{Var } L &\approx EN \text{ Var } X_0 + (EX_0)^2 \text{ Var } N \end{aligned} \qquad (6\text{-}1)$$

The expectation equation simply states that the expectation of total dollar loss in an accident is equal to the number of failures times the dollar loss per failure. There are two terms in the variance expression. The first term represents the variability due to the dollar loss per failure distribution, while the second term represents the variability in the number of failures per accident. The variance equation is not exact due to the correlation between the dollar loss per failure and the number of failures. The actual form of the computations is presented in Appendix B. Using those expressions, we derived estimates for the dollar losses in an accident, as presented in Table 6-3.

Although our methodology does not permit us to determine the precise distribution of dollar losses per accident, we developed upper bounds for these probabilities based on a standard result from probability theory. This result, which is known as the Chebyshev inequality, was used to determine upper bounds for the probability distribution of dollar losses per accident as well as upper bounds for the distribution of the dollar losses annually. The Chebyshev inequality (see, for example, Mood, Graybill, and Boes, Introduction to the Theory of Statistics, P. 71.) states that:

$$\text{Prob}\ (L \geq EL + t\sigma(L)) \leq 1/t^2$$

Thus, the probability that the risk is more than 100 standard deviations above the mean is less than or equal to 10^{-4}. Utilizing the Chebyshev inequality, we developed Table 6-4[1] which presents upper bounds for risk values.

[1]A second version of the inequality, used only for the first two entries in Table 6-4, states that

$$\text{PROB}(L \geq t(EL)) \leq 1/t$$

TABLE 6-3

STATISTICS OF ECONOMIC CONSEQUENCES FOR A SINGLE ACCIDENT

(1993)

Variable Symbol	Variable Name	Expected Value	Standard Deviation
N_o	Number of equipment failures per incident	0.0005	0.02
X_o	Dollar loss per failure	$121.50	$740.27
L	Total dollar loss per incident	6¢	$ 16.50

TABLE 6-4

UPPER BOUNDS FOR THE PROBABILITY DISTRIBUTION FOR DOLLAR LOSS PER ACCIDENT

(1993)

Dollar Loss	Upper Bound for Proability that Loss Exceeds this Value Given that an Accident Occurs
$ 6	10^{-2}
600	10^{-4}
5,250	10^{-5}
16,500	10^{-6}
161,500	10^{-8}

6.3 DERIVATION OF NATIONAL LOSS STATISTICS

The next step in the analysis was to compute the national risk profile, which requires only a knowledge of the mean and variance of dollar losses per accident. To derive the national risk profile, a two-step procedure was employed. These steps consisted of:

- Computation of the mean and the variance of the national risk profile, and
- Estimation of a probability distribution based on statistical results.

To compute the mean and the variance of the national risk profile, the following conditional expectation equations were utilized:

$$E(\overline{L}) = (EM)\ EL$$

$$\mathrm{Var}(\overline{L}) = (EM)\ \mathrm{Var}\ L + (\mathrm{Var}\ M)\ (EL)^2$$

where

L = Dollar loss per accident

$\overline{L}$ = National dollar loss

M = Number of accidental fires with CF nationally

EM = Expected value of M

EL = Expected value of L

As noted in Chapter 3, there are 311,400 fire accidents annually. Since 69.7% of these result in no release, there are 30.3% x 311,400 = 94,354 fire accidents per year resulting in a loss of carbon fibers.

Assuming that the number of accidents per year M is a Poisson random variable, then EM = 94,354, Var M = 94,354, and hence, $E\bar{L}$ = \$5,567 and $\sigma_{\bar{L}}$ = \$5,068. These statistics are summarized in Table 6-5.

The number of accidents annually is a very large number, and as a result of the statistics of large numbers, the standard deviation of the national risk is quite small. In addition, because the dollar loss on an annual national basis is the sum of losses for so many accidents, one can apply the central limit theorem and can conclude that the distribution of annual dollar loss is approximately normal. We conclude, therefore, that the annual dollar loss is very close to its expectation.

The only part of the distribution where a normal approximation may not be accurate is in the "tail" of the distribution corresponding to the high dollar losses. Since each of the individual dollar loss distributions are extremely skewed with mass in the far tail, then the annual risk profile may show a tail that diverges moderately from the tail for the corresponding normal distribution. It is uncertain exactly where the tail of the annual risk profile lies. However, we can again derive an upper bound for this tail based on the Chebyshev inequality. These results are presented in Table 6-6. The national risk profile is depicted graphically in Figure 6-2, incorporating the Chebyshev bounds for losses in excess of \$50,000.

6.4 SENSITIVITY ANALYSIS

We next examined the sensitivity of the national risk profile to input assumptions. Some of these sensitivities could be hand calculated without

TABLE 6-5

STATISTICS OF ECONOMIC CONSEQUENCES FOR ALL ACCIDENTS NATIONALLY (1993)

Variable Symbol	Variable Name	Expected Value	Standard Deviation
L	Total dollar loss per incident	6¢	$ 16.50
M	Number of incidents per year (Poisson Distribution)	94,354	307
$\overline{L}$	Total annual dollar loss	5,567	5,068

TABLE 6-6

CHEBYSHEV BOUNDS FOR NATIONAL RISK PROFILE
(1993)

Annual National Dollar Loss	Upper Bound for Probability that Loss Exceeds Value
56,250	10^{-2}
512,400	10^{-4}
5,075,000	10^{-6}

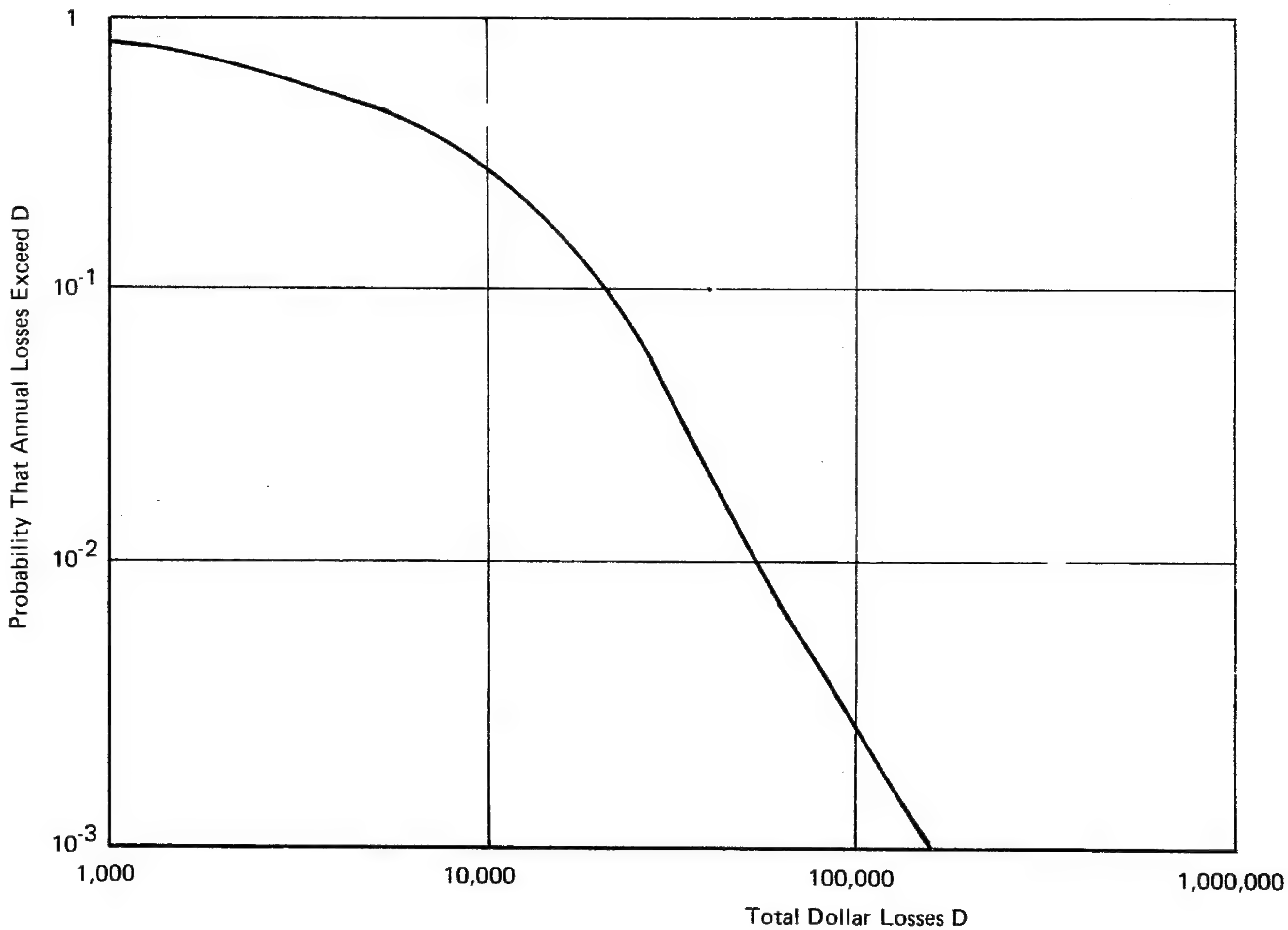

FIGURE 6–2 NATIONAL RISK PROFILE FOR MOTOR VEHICLES (1993)
(Including Upper Bounds for High Loss Probabilities)

any additional computer runs. The reason for this is that the number of failures per accident is a Poisson random variable. Hence the expected value and variance for the number of failures are approximately λ and from Equations (6-1), the expected loss per accident is:

$$\lambda \, E \, X_0$$

and the variance of loss per accident is approximately equal to

$$\lambda(E \, X_0{}^2 + \mathrm{Var} \, X_0)$$

As an example of a sensitivity analysis using these equations, suppose that the CF amounts released in an accident decrease by a factor of 10. In this case the expected numbers of failures for the various equipment classes would all decrease by a factor of 10, while the conditional probability of dollar loss given a single failure would remain the same. As a result we can make the following calculations for the loss statistics. Note that the expected national loss has decreased by a factor of 10, to \$557.

$$\lambda = .4854 \times 10^{-4}$$

$$EL = .0059$$

$$\sigma_L = 5.2$$

$$E\bar{L} = 557$$

$$\sigma_{\bar{L}} = 1602$$

The Chebyshev inequality results are tabulated in Table 6-7.

TABLE 6-7

CHEBYSHEV UPPER BOUNDS FOR SENSITIVITY ANALYSIS

WHERE RELEASE AMOUNTS DECREASE BY A FACTOR OF 10

Annual Dollar Loss for Nation	Upper Bound for Probability that Loss Exceeds Value
16,600	10^{-2}
161,000	10^{-4}
1.603 million	10^{-6}

We also examined the sensitivity for a scenario which represents an extreme worst case. We analyzed a situation where the amounts released were increased by a factor of 10 and the $\bar{E}$ values for the various categories were on average decreased by a factor of 40. In determining the $\bar{E}$ values for this worst-case scenario, it should be noted that there is a great deal of uncertainty in estimating failure levels for electronic equipment. This was the rationale for allowing individual $\bar{E}$ values for the various categories to vary up to two orders of magnitude. The dominant equipment category in this scenario was household goods and the $\bar{E}$ for household goods was decreased by two orders of magnitude. In the resulting computer analysis, household goods resulted in 95% of the failures. The relevant summary statistics and probabilities are presented in Table 6-8; the expected national annual loss increased to $1.54 million. As before, upper bounds were computed for high loss probabilities.

6.5 SUMMARY DISCUSSION OF RESULTS

The first step in the risk analysis number was to project the number of equipment failures, given that an accident occurred somewhere in the U.S. and released some quantity of carbon fibers. The expected number of failures per release incident was extremely small, resulting in an expected dollar loss per incident of only 6 cents, with a standard deviation of $16.50. The probability of any one accident resulting in losses exceeding $5,250 was estimated to be at most one in one-hundred thousand. Then based on an estimated 94,000 fire accidents per year which could potentially release CF by 1993, it was found that the expected annual loss

TABLE 6-8

STATISTICS OF WORST CASE SCENARIO (1993)

$E(\text{Failures per accident}) = .2014$

$\sigma(\text{Failures per accident}) = .794$

$E(\$|\text{failure}) \simeq \$81$

$\sigma(\$|\text{failure}) \simeq \$52$

$E(\$|\text{accident}) \simeq \$81 \times .2014 = \$16.3$

$\sigma(\$|\text{accident}) \simeq \sqrt{.2014 \times 52^2 + .794^2 \times 81^2}^{\,*} = \$68$

$E(\$|\text{year}) \simeq 94{,}354 \times \$16.3 = \$1.54$ million

$\sigma(\$|\text{year}) \simeq \sqrt{16.3^2 \times 94{,}354 + 68^2 \times 94{,}354}^{\,*} = \$21.5$ Thousand

* Based on conditional variance formula (e.g., Parzen, P. 55)

$$\text{Var } x = E_n(\text{Var } x|n) + \text{Var}_n\, E(X|n)$$

CHEBYSHEV UPPER BOUNDS FOR WORST CASE SCENARIO (1993)

Annual Dollar Loss for Nation	Upper Bound for Probability That Loss Exceeds Value
1.75 Million	10^{-2}
3.69 Million	10^{-4}
8.34 Million	10^{-5}
23.0 Million	10^{-6}

to the nation as a whole was \$5,567, with a standard deviation of \$5,068. The probability that the national loss will exceed \$512,000 was estimated to be at most one in ten thousand.

The sensitivity of these results to several input parameters was explored. The key parameter affecting the national risk is the amount of carbon fiber which could potentially be released in an accident. For example, decreasing the CF release quantities by a factor of 10 was found to decrease the national risk by about a factor of 10, to \$557. Conversely, increasing the CF released by a factor of 10 would increase the expected national risk to about \$56,000. To investigate an extremely conservative "worst case" scenario, a sensitivity run was performed with the CF release increased by a factor of 10, and with the mean exposure to failure of household equipment decreased by a factor of 100 (making it more vulnerable). In this case, the national risk was found to have an expected value of \$1.54 million per year. The chances of the national losses exceeding \$3.7 million were estimated at one in ten thousand for this scenario.

7. CONCLUSIONS

7.1 NATIONAL RISK

The results of the risk analysis indicate that the potential risks of economic losses due to CF releases from accidental fires in motor vehicles are relatively small. The expected national risk was estimated to be only about $5,600 per year for 1993, with the average loss per incident being on the order of a few cents. Furthermore, due to the high number of accidental fires per year, the national risk estimate is not subject to much variation. For example the probability of exceeding $56,000 loss in one year was estimated to be about 1/100. Although the possible consequences of a single fire can vary greatly, depending upon whether equipment failures do occur, the likelihood of such a failure is only 5×10^{-4} per incident.

It should be noted, however, that the risk estimates are subject to uncertainty from a number of different sources. The assumptions or uncertainties incorporated into the analysis are discussed below. Even when sensitivity analyses were performed to test the effect of these assumptions, the risks were found to be reasonably low in comparison to other types of risks. For example, the annual losses due to motor vehicle accidents are on the order of twenty billion dollars*, whereas the likelihood of exceeding $4 million due to CF releases in motor vehicle fires in any one year is only 10^{-4} even in the worst-case fiber release scenario.

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*Accident Facts, 1976, National Safety Council

7.2 SUMMARY OF UNCERTAINTIES

The uncertainties in the national risk estimate may be analyzed by considering the different data inputs incorporated into the model. The chief areas of uncertainty are the fraction of fibers released and the vulnerability levels of electronic equipment. However, even the most conservative scenarios in our sensitivity analyses indicate that the overall national risk is low. Some of the major areas of uncertainty are discussed below:

- Carbon fiber usage -- The projected usage could conceivably vary by a factor of 2 or 3 in terms of CF weight per auto. However, such variations are taken into account in the sensitivity analysis by varying the fraction of CF released given an accidental fire.

- Number of fibers by weight -- The present report assumes that there are 10^9 single fibers per kilogram of CF available for release, based on previous NASA estimates. Although this number could be as much as five times greater (with smaller fiber lengths), the uncertainty is again accounted for by varying the fraction of CF released.

- Fraction of CF released -- Recent tests results* indicate that the 1% figure used in our base analysis is extremely conservative, and that it is possible that no more than 0.1% of single fibers by weight would be released. Hence, the worst-case scenario, in which fiber releases were increased by an

*Tests conducted by NASA and TSC.

order of magnitude to 10%, can be considered an extreme upper bound on the true risk.

- Accident probability -- The extrapolation of Michigan data could result in about a 50% error in estimating the national accidental rate of fire in motor vehicles. Also, the number of cars carrying CF was assumed to be 57% of the fleet. The net uncertainty due to these sources might increase the total number of fires per year involving CF by a factor of about 3, which would directly multiply the expected annual national risk for 1993 of $5,600 by 3. This effect is small compared to some of the other uncertainties in the analysis.

- Equipment vulnerability -- The estimated mean failure levels could vary by several orders of magnitude, but this possibility was addressed in the high-risk scenario described in Chapter 6. The expected annual losses in this case, also assuming a ten-fold increase in CF release, were about $1.5 million for 1993.

- Economic losses -- The estimates of losses per equipment failure are subject to variations between facilities and regions, but this will contribute neglibibly to the overall uncertainty.

In summary, the sensitivity analysis indicates that the national risk could vary from a few thousand dollars to several million dollars per year with the "best estimate" expected annual loss for 1993 estimated at $5,600. Given this level of risk, even in the upper-bound scenario, it is clear that the risk is quite small compared to the approximately twenty billion dollars lost annually in automobile accidents without CF composites.

APPENDIX A

METHODOLOGY AND SYSTEM OF EQUATIONS FOR AUTOMOBILE RISK MODEL

A.1 INTRODUCTION

This appendix presents the methodology and procedure for constructing the risk profiles. The methodology applies the Poisson process to release types and is based on actual calculations of probabilities rather than a simulation. Section A.2 presents the rationale for the methodology and Section A.3 the procedure.

A.2 BACKGROUND

There were several characteristics that distinguished the automobile analysis from the air carrier analysis previously performed by Arthur D. Little. First, the collection of detailed locational data on accident scenarios (locations of accidents relative to locations of facilities) was not feasible. Second, the expected number of failed pieces of equipment per release was extremely small. Nearly all were substantially less than one.

Given these differences, a different type of methodology was used. The basis of the methodology is the computation of the expected number of failures given a release for a particular equipment type. The equation for this is:

$$N_o = \int_A n(A)\left(1 - e^{-\frac{E(A)}{E_o}}\right) dA \qquad (1)$$

where

N_o = Expected number of failures for given release

dA = Increment of surface area

A = Surface area

$n(A)$ = Density of equipment in area A

$E(A)$ = Exposure within area A

E_o = Mean exposure to failure for equipment in given area (incorporating transfer functions)

For automobile accidents, the amounts released are very small and E tends to be a great deal smaller than E_0. For example, a contour for automobile fire releases showed maximum exposures of 10^3 f·s/m^3, while most E_0 values are at least 10^7.

In view of this (1) can be approximated using Taylor series as:

$$N_o = \int n(A) \left(\frac{E(A)}{E_o}\right) dA \tag{2}$$

Although n(dA) may not be uniform, we can compute the average value of N_0 (averaged over release conditions) for a given release amount of carbon fibers by

$$\overline{N}_o = \int_r f(r)dr \int_A n(A) \frac{E(A)}{E_o} dA = \frac{\overline{n}}{E_o} \int_r f(r)dr \int_A E(A)dA \tag{3}$$

where

$\overline{N}_0$ = Expected number of failures averaged over all releases

r = Release conditions

$\frac{1}{E_0}$ = Reciprocal average exposure to failure of equipment in the county

$f(r)$ = Probability function for release conditions

and

$$\bar{n} = \frac{\int_r f(r)dr \int_A n(A) \frac{E(A)}{dA}}{\int_r f(r)dr \int_A E(A)\ dA} \tag{4}$$

In other words, $\bar{n}$ represents the average density of equipment where the averaging is over locations weighted by exposure values for the range of possible release conditions for a given amount released. Because of the random locations of accidents and random directions of wind, $\bar{n}$ can be approximated by D, the average density of equipment in the county. If it could be demonstrated that the largest concentrations of fibers generally occur at the locations of densest concentrations, then $\bar{n}$ would exceed D.

There is some intuitive rationale for this possibility. Automobile accidents, for example, tend to occur in congested areas. To investigate the possibility that $\bar{n} > D$, we looked at average city population densities weighted by population (i.e., the density of the city of the average person) and average county population densities weighted by population. The numbers are comparable, which implies that at least going from the city to county level,

$$D \simeq \bar{n} \tag{5}$$

We also note that for a given release amount,

$$\int_A E(A)\ dA = S$$

where S denotes the surface integral of exposure and is a constant.

That is, the surface integral of exposure is simply the number of fibers released times the settling velocity. Hence, no matter what the weather conditions are, all fibers contribute the same increments to the surface integral. Hence

$$\int_r f(r)dr \int_A E(A)dA = \int_r f(r)dr\ S = S \tag{6}$$

Combining (3), (5) and (6) the average number of failures for a given amount released is:

$$\overline{N}_o \simeq \frac{DS}{E_o} \tag{7}$$

This equation was the basis for the entire analysis.

In computing $\overline{N}_0$ there were two types of averaging performed. The first type was averaging the random failures given a release (i.e., the average in N_0). The second type was averaging over release conditions such as stability class, wind direction, etc.

Given the exponential failure law, then the number of failures given the average N_0 is Poisson with mean μ equal to N_0 and standard deviation $\sigma = \sqrt{N_0}$. The total variation is

$$\begin{aligned}\sigma^2 \text{ (No. failures)} &= E(\text{Var No. Failures}|N_0)\\ &+ \text{Var}(E \text{ Failures}|N_0)\\ &= EN_0 + \text{Var } N_0\end{aligned}$$

The first term EN_0 is the Poisson variation. The second term is the variation due to release condition and density variations.

We performed some computations to assess the relative influence of each type of variation. Table A-1 presents examples of total deviations for various values of EN_0. It is assumed in the Table that Var N_0 is four times EN_0, that is, the standard deviation due to release conditions and density variations is double the mean.

The table shows that the assumption of a Poisson Process with parameter $\overline{N}_0$ has virtually the same variation as the actual process. Most of the actual expectations were substantially below the values in the table. The highest expectations were household goods for the New York City counties. For these cases, the densities were on the order of 56,000 per square mile and the E_0 value, incorporating average threshold values was 3.4×10^9. Thus, the maximum $\overline{N}_0$ for a heavy truck release was

$$N_o = 56{,}000\ \text{mi}^{-2} \times \frac{1}{1609^2} \frac{\text{mi}^2}{\text{m}^2} \times .14\ \text{kg}$$

$$\times\ 10^9\ \frac{\text{f}}{\text{kg}} \div .032\ \frac{\text{m}}{\text{sec}} \div 3.4 \times 10^9\ \frac{\text{f} \cdot \text{sec}}{\text{m}^2}$$

$$= 2.8 \times 10^{-2}$$

For automobiles, the maximum $\overline{N}_0$ was an order of magnitude less. No other category except telephone exchanges and forklift equipment yields values that even come close to these household goods values. Furthermore, for the high density equipment categories, the densities and hence $\overline{N}_0$ will not show a great deal of variation with respect to release conditions.

The conclusion of this analysis is that the process can be approximated by a Poisson process with parameter N_0 as determined by Equation (7).

TABLE A-1

EXAMPLES OF VARIATION OF FAILURES

EXPECTATION EN_0	POISSON STANDARD DEVIATION	TOTAL DEVIATION
.25	.5	.7
.10	.32	.37
.05	.22	.23
.01	.1	.101
.005	.071	.071
.001	.032	.032

To account for different equipment types, compound Poisson processes were utilized whose parameters were the sums of parameters for the various equipment types.

A.3 SYSTEM OF EQUATIONS

Let

$i = 1, \ldots, N$ be the counties

$j = 1, \ldots, M$ be the equipment SIC category combinations

$k = 1, \ldots, R$ be the cases of amount released

Let

$$\lambda_{ijk} = S_k D_{ij} / E_j \tag{8}$$

where

S_k = Surface integral of exposure for release type k

D_{ij} = Density of equipment in county i

$\frac{1}{E_j}$ = Average reciprocal exposure to failure for equipment j incorporating transfer function

The λ_{ijk} is the parameter of the Poisson Process for equipment type j, county i and release type k. Then for all equipment types, the parameters for the compound Poisson Process is

$$\lambda_{ik} = \sum_j \lambda_{ijk} \tag{9}$$

Then, for automobiles

$$P_i = \text{Prob(county } i) \sim \text{Population}^{1.2}$$

$$Q_k = \text{Prob(release } k)$$

$$p(n) = \text{Prob}(n \text{ failures}) = \sum_{i,k} P_i Q_k e^{-\lambda_{ik}} \frac{(\lambda_{ik})^n}{n!} \tag{10}$$

and the average failure rate is

$$\overline{\lambda} = \sum_{i,k} P_i Q_k \lambda_{ik} \tag{11}$$

Because all of the λ values will be small, the calculations of the probabilities in (10) will be needed only for a limited set of value. In order to compute conditional risk profiles, probabilities of equipment types given a release needed to be computed. Bayes' theorem is utilized for this computation as follows. The prior probability of scenario k is

$$P_i Q_k$$

If n failures from a release are observed then the posterior probability of scenario k is

$$p(i,k|n) = \frac{p(n|i,k)p(i,k)}{\sum_{i,k} p(n|i,k)\ p(i,k)}$$

$$= \frac{P_i Q_k \, e^{-\lambda_{ik}} (\lambda_{ik})^n / n!}{\sum_{i,k} P_i Q_k \, e^{-\lambda_{ik}} (\lambda_{ik})^n / n!}$$

$$= \frac{P_i Q_k \, e^{-\lambda_{ik}} (\lambda_{ik})^n}{\sum_{i,k} P_i Q_k e^{-\lambda_{ik}} (\lambda_{ik})^n}$$

Now given n failures from one release under scenario i, k, the probability that any one being type j is

$$p(j|n,i,k) = \frac{\lambda_{ijk}}{\lambda_{ik}}$$

Thus, given n failures from one release, the probability that the scenario is i, k, and the failure is type j is

$$P(j,i,k|n)$$

$$= p(j|n,i,k) \; p(i,k|n) = \frac{P_i Q_k \, e^{-\lambda_{ik}} (\lambda_{ik})^n \; \frac{\lambda_{ijk}}{\lambda_{ik}}}{\Sigma P_i Q_k \, e^{-\lambda_{ik}} (\lambda_{ik})^n} = \frac{P_i Q_k \, e^{-\lambda_{ik}} (\lambda_{ik})^{n-1} \lambda_{ijk}}{\Sigma P_i Q_k \, e^{-\lambda_{ik}} (\lambda_{ik})^n}$$

Thus,

$$p(j|n) = \sum_{i,k} p(j,ik|n)$$

$$= \frac{\sum_{i,k} P_i Q_k \, e^{-\lambda_{ik}} (\lambda_{ik})^{n-1} \, \lambda_{ijk}}{\sum_{i,k} P_i Q_k \, e^{-\lambda_{ik}} (\lambda_{ik})^{n}} \tag{12}$$

For the case n = 1, it is seen that

$$p(j|1) \simeq \overline{p}_j = \frac{\lambda_j}{\overline{\lambda}} \tag{13}$$

where

$$\overline{\lambda}_j = \sum_{i,k} P_i Q_k \lambda_{ijk}$$

The computation of the risk profile is based on the expressions for p(n) and p(j|n).

APPENDIX B

DETAILS ON VARIANCE OF DOLLAR LOSS PER ACCIDENT

To determine the dollar loss statistics given an accident, it is necessary to condition the calculation on the number of failures. Thus:

$$EL = \sum_{i=1}^{\infty} p(i)\ E(L|i)$$

and

$$EL^2 = \sum_{i=1}^{\infty} p(i)\ E(X^2|i)$$

and

$$\text{VAR } L = EL^2 - E(L)^2$$

Because expectations are additive

$$= \sum_{i=1}^{\infty} i\ p(i)\ E(X_o|i)$$

$$= EX_o\ EN_o$$

For the variance computation, by considering the individual scenario probabilities

$$EL^2 = \sum_{j=1}^{\infty} p(j) \sum_{i,k} P_i\ Q_k\ (j\ \text{Var}\ (X_o|i,j,k)) + j^2 E\ (X_o|i,j,k)^2$$

P_i and Q_k are the scenario probabilities (See Appendix A) and the statistics of X_0 given i,j,k are based on the failure rates for each equipment class and scenario. An alternate expression for EL^2 can be obtained by considering the covariance of two separate losses given i failures.

$$EL = \sum_{j=1}^{\infty} p(j) \left(i \operatorname{Var}(X_0|i) + i^2 E(X_0|i) + i(i-1) \operatorname{cov}_i\right)$$

where

cov_i = covariance of two separate losses given i failures

The approximate expressions given in Chapter 6 assume that cov_i is zero and that the distribution of $(X_0|i)$ is independent of i. These assumptions are important only if $i > 1$. Since the probability of multiple failures is very low, the approximate expression is virtually identical to the exact expression.

APPENDIX C

EQUIPMENT DATA

Facility Category	Equipment Category Number	Equipment	$\bar{E}$	Number of Pieces Factor	Number of Pieces Index **	$ Cost Per Piece
Households	1	TV/Stereo White Goods Furnace	3.4E+09	5.0E+00	04	80
Police	2	Motor Generator	1.0E+06	1.0E+00	01	98
	3	Radio Trans. in Veh.	2.0E+08	8.5E-04	03	250
	4	Teletype Mach. Misc. Eqpt.	2.4E+08	1.9E-05	03	108
	5	Small Computer Line Printer Small Computers Large Computer	1.1E+09	1.1E-05	03	4489
	6	PBX (Small)	1.8E+09	2.2E-05	03	9800
	7	CRT Terminals Radio Control Console	2.4E+09	7.4E-05	03	113
Fire	8	Motor Generator (large)	1.5E+06	1.0E+00	01	9
	9	Motor Generator (small)	1.5E+07	2.0E+00	01	20
	10	PBX (small)	7.3E+07	1.0E+00	01	1040
	11	Radio Trans. in veh.	2.0E+08	3.1E-04	03	80
	12	Radio Control Console	5.0E+08	7.8E-06	03	80
	13	Radio Trans-ceivers	9.0E+08	4.7E-06	03	250
Post Office Sorting Center	14	Sorter with OCR Sorter w/o OCR	2.5E+08	2.2E-05*	03	800

*Truncate

**Indexes in Appendix

Facility Category	Equipment Category Number	Equipment	$\bar{E}$	Number of Pieces Factor	Number of Pieces Index	$ Cost Per Piece
Subway	15	Auto. Fare Coll.	3.3E+07	1.0E-02	07	250
	16	Radio	2.5E+08	0.5E+00	07	80
	17	Sch. Syst.- Sm. Comp.	2.8E+08	5.0E-03	07	800
		PBX (small)				
R.R. Terminal	18	Mobile Trans.	3.9E+08	2.0E+01	20	80
	19	PBX (small)	5.4E+08	1.0E+00	20	800
	20	CRT Terminals	7.9E+09	1.8E+01	20	137
		Radio Control Console				
		Transceivers				
General Manufacturing*	21	Var. Freq. Cont.	1.0E+09	1.0E-02	09	15,200
	22	Digital Speed Control	2.0E+09	3.3E-03	09	1,700
	23	Transf. Sub. Switch	6.3E+09	2.7E-03	09	65,800
	24	Fork Lift Trucks	1.7E+07	3.3E-02	09	80
		Battery Charger-Truck				
	25	Programmable Palletizer	1.7E+08	1.7E-03	09	250
	26	Inj. Mold Heater Controls	3.3E+08	4.0E-02	09	80
	27	Quality Control Instr.	3.3E+09	3.3E-02	09	250
		Computer Facility (small)	3.3E+09	2.0E+00	08	800
		PBX (small)				

*Equipment categories 21-22 from SIC 2824; 23 from SIC 3714; 24-28 from SIC 2844

Facility Category	Equipment Category Number	Equipment	$\bar{E}$	Number of Pieces Factor	Number of Pieces Index	$ Cost Per Piece
Manufacturer of Electronic Equipment	29	In process spray paint	1.3E+07	5.9E-04	13, 15 17, 11	3,760
	30	In process plaster parts	2.0E+07	5.9E-04	13, 15, 17, 11	2,420
	31	Master Oscillator Controller	1.4E+03	2.4E-03	13, 15, 17, 11	8,838
		Incomping Insp. Test Eqpt.				
	32	Assembly Line Signal Inter.	2.5E+08	4.1E+00	13, 15, 17, 11	1.16
		In process elect. comp.				
		In process burn-in				
	33	Inj. mold temp & pressure	5.0E+08	1.2E-02	13, 15, 17, 11	1,800
	34	In process life test	3.3E+09	5.9E-02	13, 15 17, 11	2.50
Telephone Co.	35	Switching Center	1.4E+09	1.0E+00	04	0.065

Facility Category	Equipment Category Number	Equipment	$\bar{E}$	Number of Pieces Factor	Number of Pieces Index	$ Cost Per Piece
Radio/TV	36	Mobile Mini Cam	1.9E+07	3.0E+00	22, 24	2,500
	37	Studio Eqpt. Transf. & Transm Control Room PBX (small)	4.0E+08	4.0E+00	22, 24	1,225
General Merchandise Retailers	38	Motor generator (large)	1.8E+06	2.0E-03	27, 31 33, 35	8
	39	PBX (small)	7.7E+08	1.0E+00	26, 30 32, 34	800
	40	POS Terminals	2.5E+09	2.0E-01	27, 31 33, 35	250
	41	HVAC Controls	7.7E+09	4.0E-03	27, 31 33, 35	80
Retail Grocers	42	POS Terminals HVAC Controls	1.0E+09	1.4E+01	28	226
Finance & Insurance	43	PBX (small)	3.3E+09	1.0E+00	36, 38 40, 42	800
Computer Services	44	PBX (small)	2.3E+08	1.0E+00	44	800
	45	Gen. Office Eqpt.	2.8E+09	1.0E+00	45	30
	46	Computer (large)	2.9E+09	1.0E+00	44	8,500
Electronic R&D, Univ.	47	PBX (small)	3.3E+09	1.0E+00	46, 50	800
	48	Instruments	3.3E+09	1.0E+00	47, 51	80
Hospitals	49	Generator (large)	5.0E+06	1.0E+00	48	300
	50	Gen. Instr. Patient Area	1.5E+08	1.8E-01	05	250
	51	PBX	3.0E+09	1.0E+00	48	800
	52	X-Ray	6.0E+09	5.5E-03	05	800

Facility Category	Equipment Category Number	Equipment	$\bar{E}$	Number of Pieces Factor	Number of Pieces Index	$ Cost Per Piece
Airports	53	TTY at Terminal	2.0E+09	4.1E-04	06	250
	54	ASR	2.0E+09	*		2500
	55	Computer at Tower	3.1E+09	*		800
	56	Consoles at Tower	3.1E+09	4.7E-05	06	250
Auto & Truck Assembly	57	Spray Paint Drying Tunnel	5.7E+04	2.5E-04	19	12080
	58	Spot Welder Controls	3.3E+06	1.3E-02	19	1700
	59	Prog. Auto. Welders	9.8E+07	5.0E-04	19	12800
	60	Assembly Line Controllers	9.8E+07	5.0E-04	19	12800
	61	Welder Controls	1.0E+03	5.0E-04	19	1900
	62	PBX (small)	1.0E+09	1.0E+00	18	800
	63	Computer System (large)	1.0E+09	1.0E+00	18	12800

*Set to 1 if category 06 $\geq$ 1,000

APPENDIX D

DEMOGRAPHIC DATA INDICES

Index	Demographic Data Category
1	Dummy Variable = 1 Per County
2	Area
3	Population
4	Families
5	Hospital Beds
6	Air Carrier Operations
7	Number of Subway Cars
8-9	Facilities, Employees SIC Code 1900
10-11	Facilities, Employees SIC Code 3573
12-13	Facilities, Employees SIC Code 3650
14-15	Facilities, Employees SIC Code 3660
16-17	Facilities, Employees SIC Code 3670
18-19	Facilities, Employees SIC Code 3710
20-21	Facilities, Employees SIC Code 4011
22-23	Facilities, Employees SIC Code 4830
24-25	Facilities, Employees SIC Code 4890
26-27	Facilities, Employees SIC Code 5310
28-29	Facilities, Employees SIC Code 5410
30-31	Facilities, Employees SIC Code 5600
32-33	Facilities, Employees SIC Code 5700
34-35	Facilities, Employees SIC Code 5900
36-37	Facilities, Employees SIC Code 6020
38-39	Facilities, Employees SIC Code 6100
40-41	Facilities, Employees SIC Code 6200
42-43	Facilities, Employees SIC Code 6300
44-45	Facilities, Employees SIC Code 7370
46-47	Facilities, Employees SIC Code 7391
48-49	Facilities, Employees SIC Code 8060
50-51	Facilities, Employees SIC Code 8220

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16. Abstract

A risk assessment was conducted to estimate the potential losses through 1993 due to the usage of carbon fiber (CF) composites in U. S. motor vehicles, including automobiles and trucks. Motor vehicle fires could conceivably release minute carbon fibers, which might disperse in the atmosphere, penetrate buildings or enclosures, and cause damaging shorts to electronic equipment. Of a total estimated 310,000 vehicle fires per year in the U. S., approximately 94,000 could potentially release carbon fibers. The average mass released was estimated to be about 20 grams per incident, based on forecasts of CF usage through 1993 and experimental tests with burning CF composites. A methodology was developed to compute estimated dollar losses, incorporating data on the geographic distribution of potentially vulnerable facilities, as well as the mean CF exposure levels at which various equipment would fail. The results were then statistically aggregated to produce a national risk profile for estimated annual losses in 1993. The expected loss was $5,567 per year (1977 dollars), and the likelihood of exceeding $500,000 in annual losses was estimated to be at most one in ten thousand.

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